6.3 ARCHITECTURAL COMPONENTS

6.3.1 EXTERIOR WALL COMPONENTS

6.3.1.1 ADHERED VENEER

Adhered veneers are typically thin materials such as tile, masonry, stone, terra cotta, ceramic tile or stucco that are attached to a backing substrate using an adhesive. These may pose a significant falling hazard.

TYPICAL CAUSES OF DAMAGE

- Adhered veneers are generally deformation sensitive and may crack or become dislodged due to deformation of the backing substrate. Adhered veneers placed directly over shear walls or structural elements that are designed to undergo large deformations may be particularly vulnerable.
- Poorly adhered veneer may come loose due to direct acceleration. This may be a particular problem where the adhesive bond has deteriorated due to water intrusion or degradation of the backing substrate.

Damage Examples

Figure 6.3.1.1-1 Failure of adhered masonry veneer at the Atascadero City Hall in the 2003 magnitude-6.5 San Simeon Earthquake (Photo courtesy of Mike Mahoney, FEMA).

Figure 6.3.1.1-2 Close-up of failed adhered veneer. (Photo courtesy of Eduardo Fierro, BFP Engineers).

Figure 6.3.1.1-3 Cracked and spalled adhered veneer reveals incipient structural damage to concrete piers in Viña del Mar following the 2010 magnitude-8.8 Chile Earthquake. In this case, the areas of structural and nonstructural damage coincide; the adhered veneer remained intact over portions of the shear wall that did not deform significantly (Photo courtesy of Santiago Pujol, Purdue University).

Figure 6.3.1.1-4 Failed adhered veneer fallen from parapet in Santiago following the 2010 magnitude-8.8 Chile Earthquake. (Photos courtesy of Antonio Iruretagoyena, Rubén Boroscheck & Associates)

SEISMIC MITIGATION CONSIDERATIONS

- Repair any cracked or loose veneer; repair any damage or deterioration of the backing substrate.
- Remove adhered veneer above exits or pedestrian walkways, especially larger units if they are mounted above 10 feet.
- Design a structural canopy to resist the weight and impact of falling veneer; particularly above exits or walkways.
- Restrict pedestrian access below the veneer by providing a barrier or wide landscaping strip.
- Provide positive connections to attach the veneer to the structure; see Figure 6.3.1.2-5, in the Anchored Veneer example or Figure 6.3.3.1-3 in the Interior Veneer example.

Mitigation Examples

Figure 6.3.1.1-5 Landscaping strip restricts pedestrian access adjacent to adhered veneer façade. Larger units used within lower 6 feet; smaller units used above (Photo courtesy of Cynthia Perry, BFP Engineers).

MITIGATION DETAILS

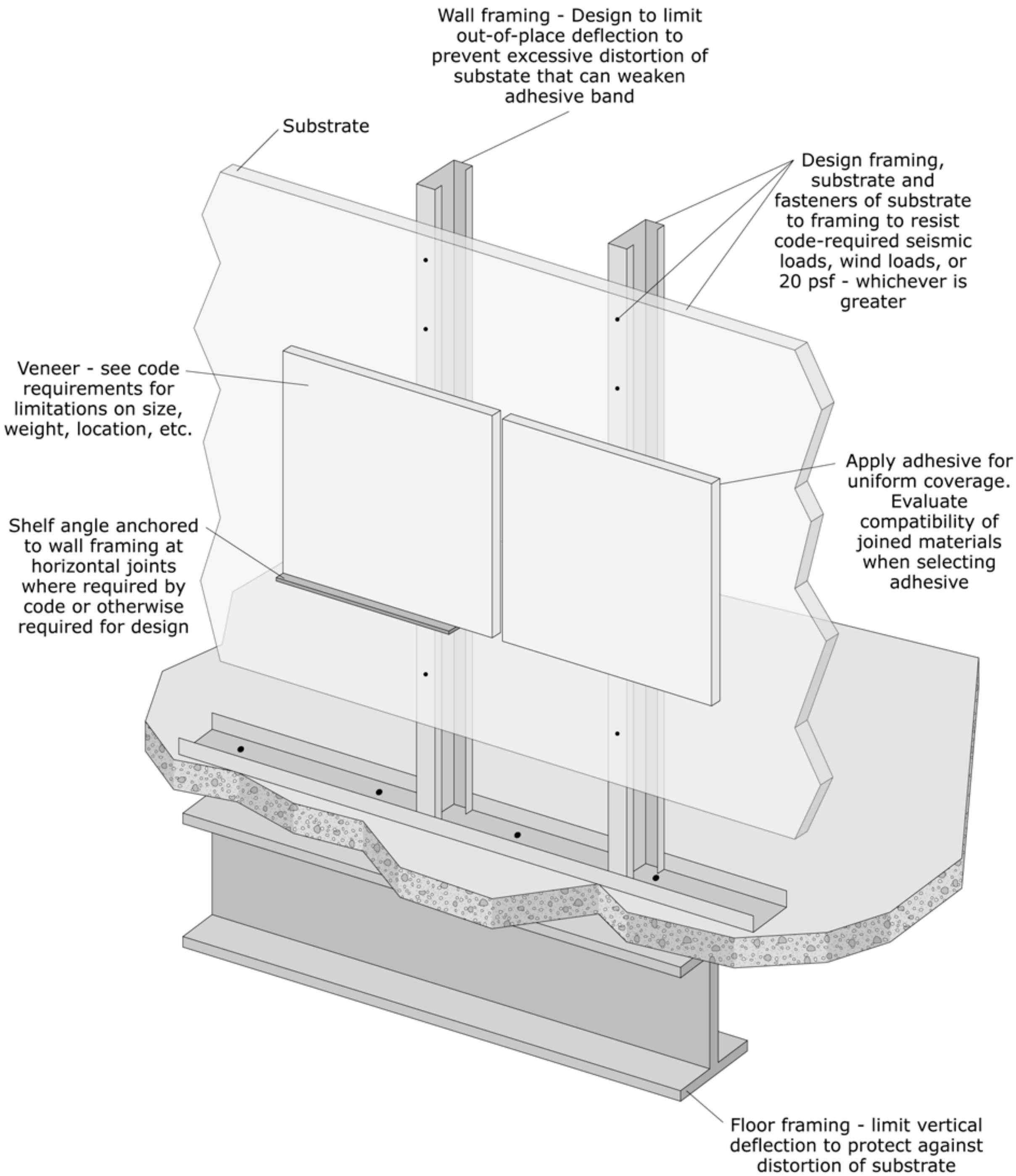


Figure 6.3.1.1-6 Adhered veneer (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.1 EXTERIOR WALL COMPONENTS

6.3.1.2 ANCHORED VENEER

Anchored veneers are typically masonry, stone or stone slab units that are attached to the structure by mechanical means. These units and their connections must be designed to accommodate the anticipated seismic drift; otherwise they may pose a significant falling hazard.

TYPICAL CAUSES OF DAMAGE

- Anchored veneers and their connections may be damaged by inertial forces and by building distortion; units located at corners and around openings are particularly vulnerable.
- Rigid connections may distort or fracture if they do not have sufficient flexibility to accommodate the seismic drift; veneer units may crack, spall, or become completely dislodged and fall.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertightness at joints is important for the longevity of the anchors.

Damage Examples

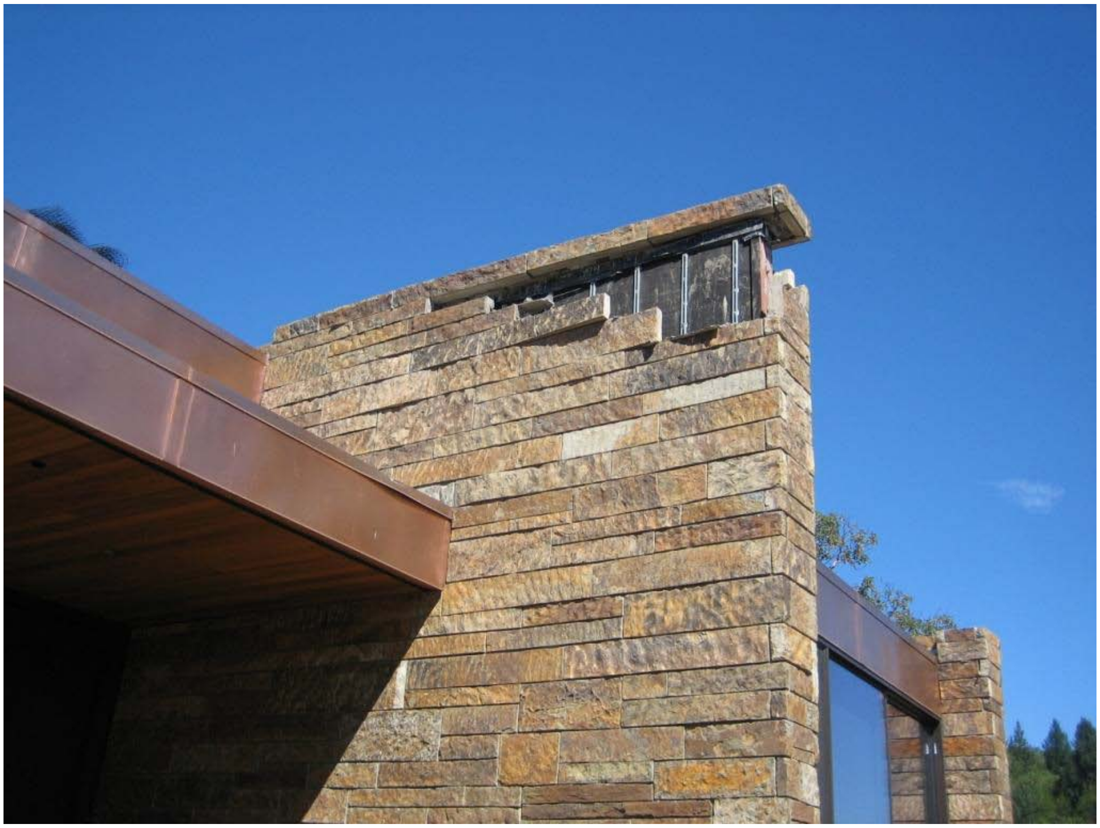


Figure 6.3.1.2-1 Fallen sandstone veneer as a result of a magnitude-4.4 earthquake in northern California. Post-earthquake investigation revealed missing dovetail anchors, missing pencil rods, and weak stone-to-mortar bond (Photo courtesy of Simpson Gumpertz and Heger).

Figure 6.3.1.2-2 Fallen sandstone veneer as a result of a magnitude-4.4 earthquake (Photo courtesy of Simpson Gumpertz and Heger).

Figure 6.3.1.2-3 Rubble from failed anchored veneer as a result of the 1994 Northridge Earthquake (Photo courtesy of Robert Reitherman).

SEISMIC MITIGATION CONSIDERATIONS

- ASCE/SEI 7-10, *Minimum Design Loads for Buildings and Other Structures (*ASCE, 2010), contains a number of prescriptive requirements and limitations on the use of anchored veneer. These include height limits, drift limits, deflection limits, limits on the use of combustible structural supports such as wood, limits on basic wind speed, cavity size limits, mortar bed minimum thickness limits, and minimum tie spacing limits. Check the applicable code requirements when considering seismic mitigation options.
- Existing veneer anchors should be checked periodically and corroded anchors should be replaced. Tie spacing should be compared with current code requirements to evaluate whether the anchorage is sufficient. Additional anchors may reduce the falling hazards.
- There are many vendors who supply veneer anchors; these are typically metal wires or clips with a positive attachment to the structural backing that are embedded in the veneer mortar bed. The seismic version of these anchors requires an additional horizontal wire placed in the mortar bed and attached to the anchor. Some examples of these seismic veneer anchors are shown, others can be found online.

Mitigation Examples

Figure 6.3.1.2-4 Installation of stone veneer showing anchorage to steel dovetail clips which are fastened to steel studs bolted to the grouted reinforced masonry wall behind (Photo courtesy of Simpson Gumpertz and Heger).

MITIGATION DETAILS

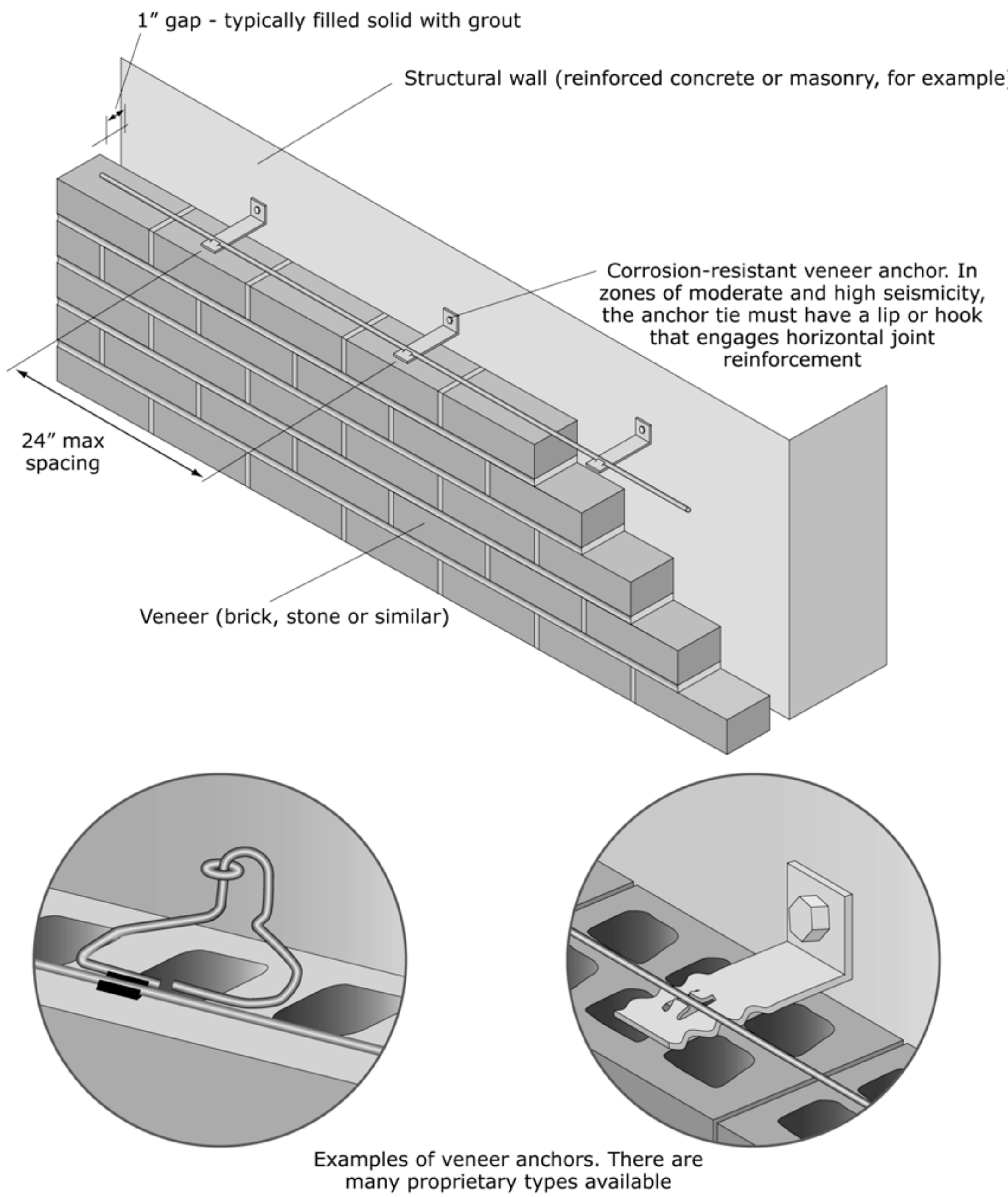


Figure 6.3.1.2-5 Anchored veneer (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.1 EXTERIOR WALL COMPONENTS

6.3.1.3 PREFABRICATED PANELS

This category covers any type of prefabricated exterior panel that is attached to the perimeter structural framing. These may be lightweight metal panels or precast concrete panels that may have adhered or anchored veneer.

TYPICAL CAUSES OF DAMAGE

- Both lightweight and heavier panels may be damaged by deformations of the building frame; heavier panels may also be damaged by direct acceleration.
- Unless the panel connections are specially detailed to allow the panel to move independently of the building, both the connections and the panel may be damaged. Panels may be racked, damage adjacent panels, connections may fracture, and panels may become dislodged or displaced.
- Deterioration or corrosion of the mechanical connections is a significant concern; corroded connections may fail prematurely. Maintaining watertight joints is important for the longevity of the anchors.

Damage Examples

Figure 6.3.1.3-1 Failure of precast panel at parking garage that resulted in fatality in the 1987 magnitude-5.9 Whittier, California earthquake (Photo courtesy of Degenkolb Engineers).

Figure 6.3.1.3-2 Precast panel failure at the top floor of a hospital in the1994 magnitude-6.7 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-3 Precast panel damage at a building corner in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-4 Interior view of precast panel showing response of three sets of push-pull connections in the 1994 Northridge Earthquake (Photo courtesy of OSHPD).

Figure 6.3.1.3-5 Close-up photo of two fractured connection bolts in a prefabricated panel in the 1994 Northridge Earthquake; corrosion of the rods may have contributed to the failure. (Photo courtesy of OSHPD).

Figure 6.3.1.3-6 Residential building with precast concrete corridor and balcony railing panels. Some panels were damaged and subsequently many were removed to prevent falling. Location in Rancaqua, Chile 154 miles northeast of the epicenter; estimated PGA of 0.3g during the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroschek & Associates).

Figure 6.3.1.3-7 Numerous precast panels removed to prevent falling; detail from residential building in Rancagua, Chile above. These panels had a bearing seat at the center and supported on steel dowels at either end (Photo courtesy of Eduardo Fierro, BFP Engineers).

SEISMIC MITIGATION CONSIDERATIONS

- Precast panel connections and panel joints require specialized design based on the expected inter-story drift of the structural system supporting them or 0.5 inch, whichever is greater. The connections must be detailed with sufficient ductility and rotation capacity to prevent failure. Typically, the panels are seated on two bearing connections at either the top or bottom floor and then have “push-pull” connections at the adjacent floor which resist out-of-plane loading but move laterally in the plane of the panel. In this way, the panels move with the floor where the bearing connections are located and the drift is accommodated by the rod at the “push-pull” connection.
- Architectural Design for Earthquake, A Guide to Nonstructural Elements, (Charleson, 2007) has a detailed discussion of issues related to exterior cladding. Sliding connections with slotted or oversized holes are commonly used in New Zealand as an alternative to push-pull connections.

MITIGATION DETAILS

Figure 6.3.1.3-8 Precast spandrel panel in San Francisco parking garage supported by bearing connections near top of panel (left) and slotted connections at bottom of panel (right); panels have four connections each. The remnants of a previous nonductile connection detail are visible in the photo at left (Photo courtesy of Cynthia Perry, BFP Engineers).

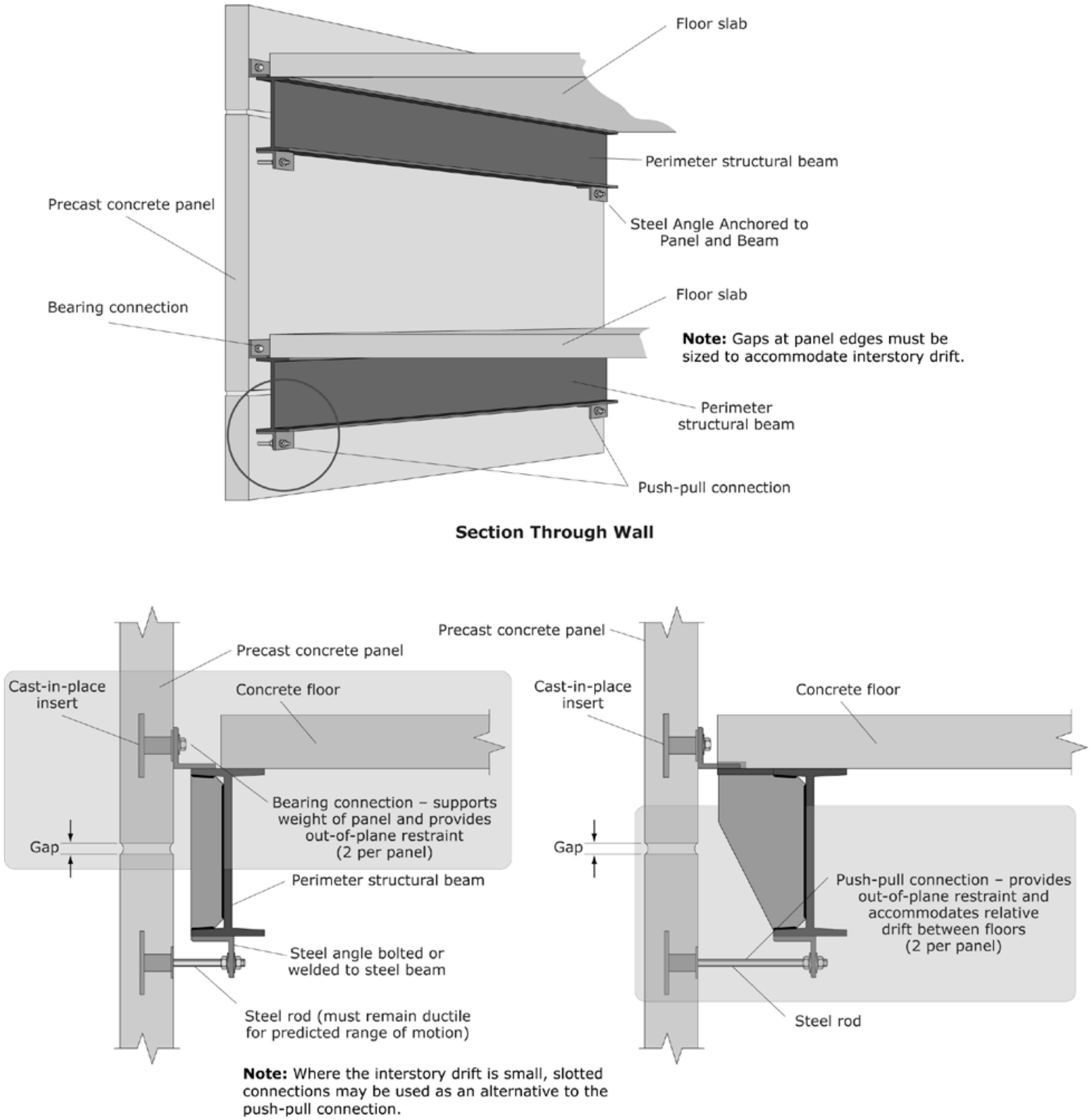


Figure 6.3.1.3-9 Prefabricated panels (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.1 EXTERIOR WALL COMPONENTS

6.3.1.4 GLAZING

Glazing includes glass curtain walls on multistory buildings, large storefront windows, as well as small, operable wood framed windows. Glass may be annealed, heat-strengthened, tempered, laminated or in sealed, insulating glass units. Glazing can be installed using either wet or dry glazing methods. Any of these may pose a significant falling hazard if not designed to accommodate seismic forces and displacements.

TYPICAL CAUSES OF DAMAGE

- Glazing assemblies are sensitive to both accelerations and deformations and are subject to both in-plane and out-of-plane failures. Glazing is particularly vulnerable in flexible structures with large inter-story drifts; large storefront windows are also vulnerable. Glass can fall in shards, shatter into small pieces, or broken panes may be held in place by film.

Damage Examples

Figure 6.3.1.4-1 Shard of broken untempered glass that fell several stories from a multistory building in the 1994 Northridge Earthquake (Photo courtesy of Wiss, Jenney, Elstner Associates).

Figure 6.3.1.4-2 Scenes in Ferndale, California following the 2010 magnitude-6.5 Eureka Earthquake. 50% of the glazing on Main Street was cracked (Photos courtesy of Bret Lizundia, Rutherford & Chekene).

Figure 6.3.1.4-3 Glazing damage was observed in many residential and commercial buildings and hospitals throughout central Chile following the 2010 magnitude-8.8 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

Figure 6.3.1.4-4 Glazing damage, due in part to pounding with the structure at right during the 2010 Chile Earthquake (Photo courtesy of Antonio Iruretagoyena, Rubén Boroscheck & Associates).

Figure 6.3.1.4-5 Overhead glazing damage from the 2010 Chile Earthquake (Photo courtesy of Eduardo Miranda, Stanford University).

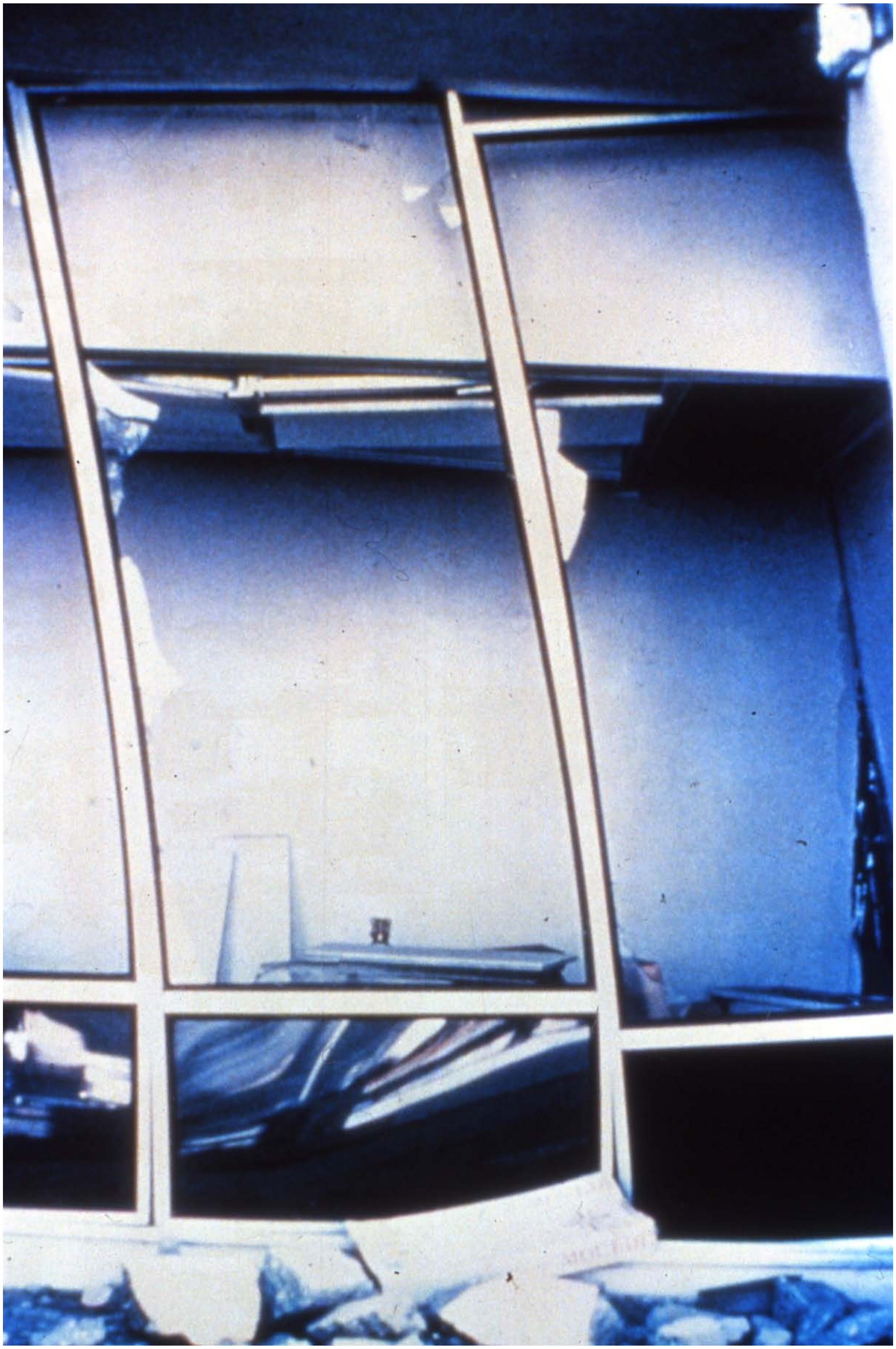


Figure 6.3.1.4-6 Broken glass and bent window mullions in flexible building which experienced large inter-story drift in the 1994 Northridge Earthquake (FEMA 310, 1998).

SEISMIC MITIGATION CONSIDERATIONS

- The design of glazing assemblies depends on the calculated inter-story drift for the building. Glazing generally performs better with stiffer structural systems that have lower inter-story drift or where larger edge clearances are provided at the mullions. The building code ASCE/SEI 7-10 and rehabilitation standard ASCE/SEI 41-06 *Seismic Rehabilitation of Existing Buildings,* (ASCE, 2006) include minimum requirements for $\Delta_{fallout}$, the relative displacement that causes the glass to fall from the glazing assembly, as a multiple of the design displacement and the importance factor.
- The term safety glass refers to tempered or laminated glazing and is required by code in a number of applications such as glazing in or adjacent to exits, within 10' of a walking surface, etc. ANSI A97.1 *Safety Glazing Materials Used in Buildings* (ANSI, 2004) is the standard that defines different kinds of safety glass. Use of tempered glass will greatly reduce the seismic hazard because tempered glass breaks into small dull fragments instead of large hazardous shards. Tempered glass is required within 10' above a walking surface under some circumstances; check applicable code requirements. Laminated glass will typically remain in place when broken and will prevent people or objects from falling through the opening. Wired glass with a grid of steel wire embedded in the pane is an option for some situations where fire and impact rating are not also required. Storefront windows are often vulnerable as the windows occupy a large structurally unsupported area at the ground floor, often resulting in soft story or torsion problems. Use of laminated glass for storefront windows reduces the seismic risk and also increases protection from burglary and vandalism.
- Plastic films that help hold glass fragments together even if the pane breaks are available. These films may reduce the seismic risk particularly where glazing is directly over an exit way, within 10' of an exit way, or along interior corridors. Such films may be a cost effective way to retrofit an existing pane of glass and are often installed for other reasons, such as security or reducing solar heat gain. Extending the film over the edge of the surrounding frame is advisable not only to hold broken fragments in place but also to prevent the entire pane from falling out.
- Avoid placing beds, desks, chairs or couches that are typically occupied many hours a day near large plate glass windows.
- Liberal use of landscaping strips or areas with restricted pedestrian access may help to reduce the seismic risk beneath large glass panes or tall curtain walls.

MITIGATION DETAILS

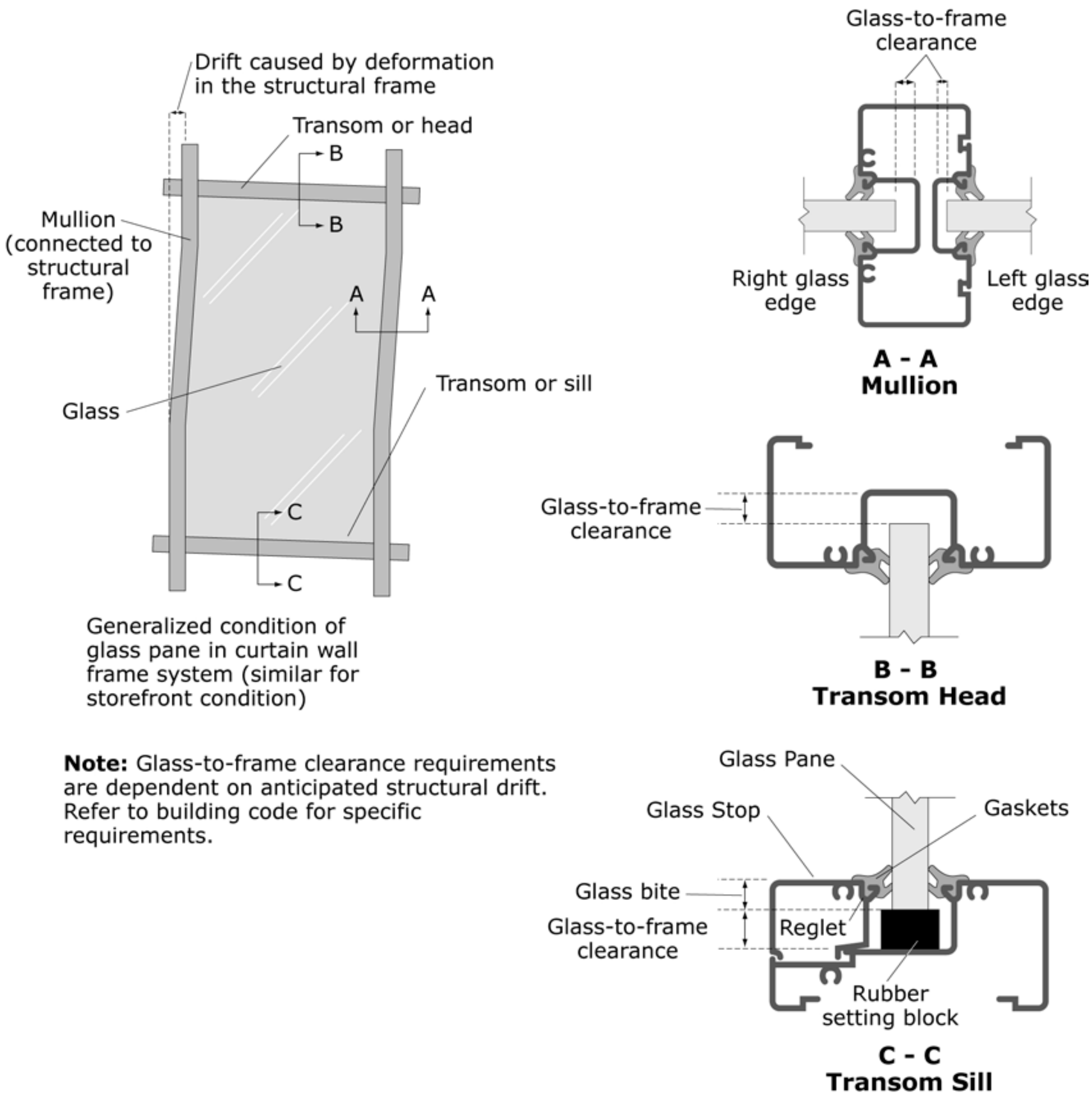


Figure 6.3.1.4-7 Glazed exterior wall system (ER).

6.3 ARCHITECTURAL COMPONENTS

6.3.1 EXTERIOR WALL COMPONENTS

6.3.1.5 GLASS BLOCK

Glass block, or glass unit masonry, is used to construct a variety of nonbearing walls or used as nonbearing infill in window openings. If not properly detailed to accommodate movement, glass block units may break and pose a falling hazard.

TYPICAL CAUSES OF DAMAGE

- Glass block panel assemblies are subject to both in-plane and out-of-plane failures. If the glass block panels are not reinforced and isolated from the movement of the structural surround or structural supports, the panel consisting of brittle glass blocks may be damaged. Older glass block panels may be installed with rigid mortar along all four sides and in the mortar joints. Damage to these rigid installations, or installations without the capacity to accommodate seismic deformations, may result in glass block breakage, falling glass block units, or possibly failure of the whole panel.
- If glass block panels are rigidly attached at the sill with mortar, but allowed to slip along the top and sides, and installed with panel reinforcing in alternate mortar joints, there may be damage to the panel anchors, angles, or channels surrounding the panel. The fire-rating or weatherproofing may also be compromised and should be inspected if there are signs of movement.
- A survey of glass block installations after the 1994 Northridge Earthquake found that glass block panels installed per the UBC provisions since the late 1970’s had performed well (Hart, 1994).

Damage Examples

Figure 6.3.1.5-1 Damage to glass block in building with reinforced concrete frame and concrete masonry infill in the magnitude-7 2010 Haiti Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). Note some blocks failed at rigid mortar joints and stayed in the frame, others fell out of the frame, and others broke in place. This building also suffered structural damage.

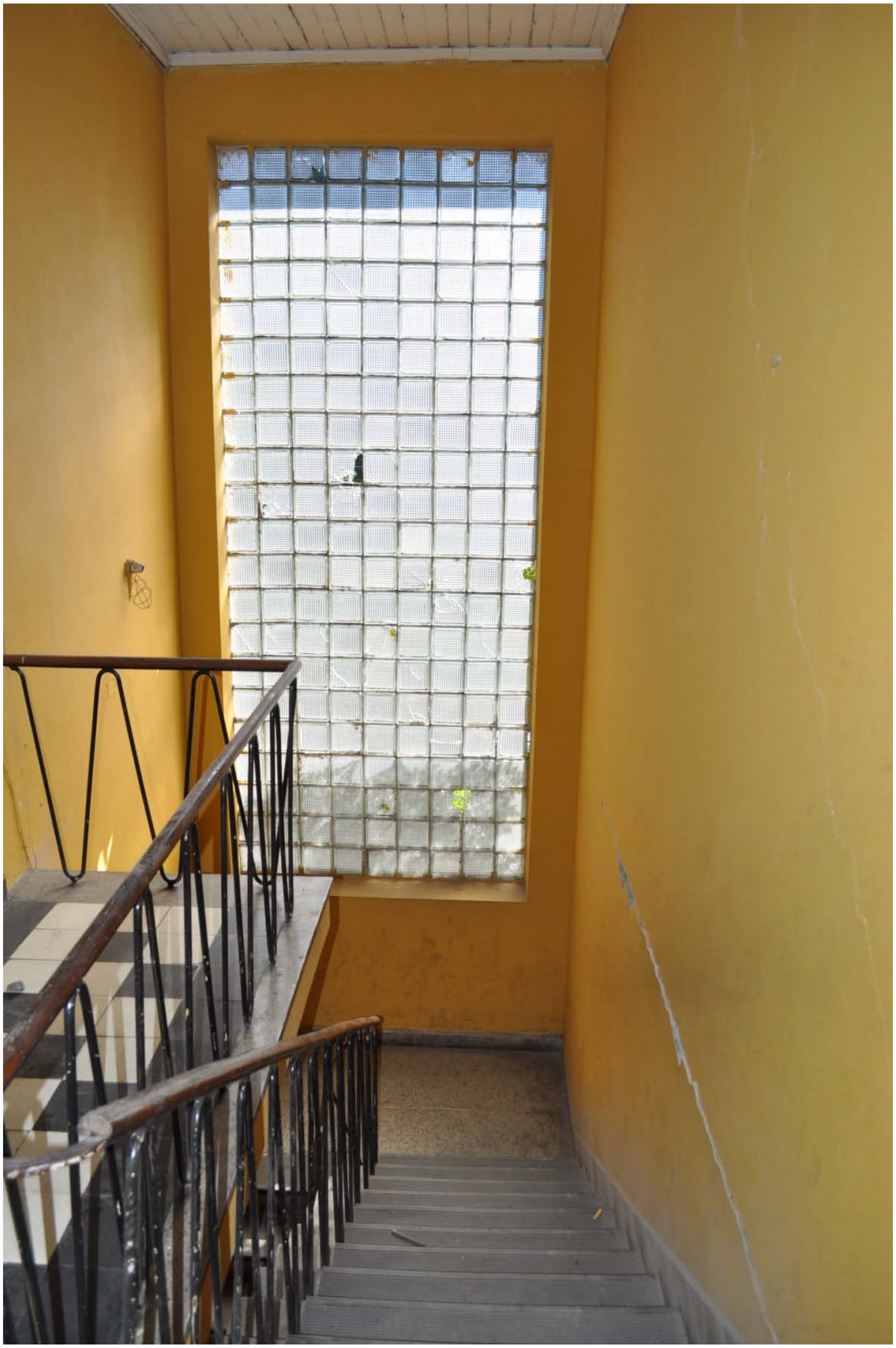


Figure 6.3.1.5-2 Damage to glass block with rigid mortar on all sides and in all joints in the 2010 Chile Earthquake (Photo courtesy of Eduardo Fierro, BFP Engineers). About 25% of the glass block units are cracked or broken but entire panel will need to be removed and replaced.

Figure 6.3.1.5-3 Damaged glass block panel from the Los Angeles Hospital in the 2010 Chile Earthquake; relatively new hospital building that had to be evacuated for repairs (Photo courtesy of Bill Holmes, Rutherford & Chekene). Blocks were installed with steel reinforcing bars in the top and bottom horizontal joints.

SEISMIC MITIGATION CONSIDERATIONS

- The design of glass block panels must meet code requirements for unit masonry construction in ACI 530-08, *Building Code Requirements and Specification for masonry Structures and Related Commentaries* (ACI, 2008), except as modified by Section 14.4 of ASCE 7-10, *Minimum Design Loads for Buildings and other Structures* (ASCE, 2010), as well as code requirements in Chapter 13 for nonstructural walls, but they are not subject to the provisions that apply to standard glazing assemblies. The glass block panel should be isolated for seismic, wind and thermal movement from the nonstructural surround, and the nonstructural surrounding wall should be isolated from the seismic inter-story drift of the structure.

- ASCE/SEI 7-10 contains prescriptive requirements such as limiting panel size (144 sf for standard units in exterior panels; 250 sf for interior panels), maximum panel dimensions between structural supports (25 ft in width or 20 ft in height), and lateral support (along top and sides at not more than 16 in on centers). There are additional code limitations on material properties of the glass unit masonry, sealant, and mortar; and properties, spacing, and details of anchorage hardware; and spacing and details of expansion joints. There also are deflection limits on the structural walls or framing that surrounds the panels at the head (lintel) and jambs. Seismic design forces on the nonbearing wall assembly are determined from ASCE/SEI 7-10 as for other nonstructural walls.
- For seismic resistance, the panels must be supported for both in-plane and out-of-plane loads but should be isolated from the movement of the surrounding structure. Glass block units are inherently brittle and must be supported in a manner that does not allow structural loads from the building to be transmitted to the glass blocks. This typically involves providing a rigid mortar attachment to the sill at the bottom of the panel and providing slip joints along the top and sides. In addition, horizontal reinforcing is placed in alternate mortar joints. Typical glass block panel details are shown in Figure 6.3.1.5-6. Slip joints at the top and sides may be accomplished with steel angles, steel channels, or panel anchors (see three alternate head details in Figure 6.3.1.5-7). Jamb details are similar.
- Note that the fire-rated head detail A in Figure 6.3.1.5-7 is very similar to Figure 6.3.2.1-6 used for full-height heavy partitions. This type of detail with steel angles provides the most robust seismic restraint where large displacements are expected.
- Special care must be taken to detail glass block panels on intersecting planes such as corners or reentrant corners. Simultaneous motion in two directions makes these joints particularly vulnerable to damage.
- Glass block vendors often have proprietary hardware, standard specifications, and standard downloadable details available to assist designers. Manufacturer's standard slip joint details are typically designed to accommodate thermal expansion and wind forces and may not have not been explicitly designed for seismic deformations. Thus, these details should be used with caution if large inter-story drifts are expected.
- It may be prudent to avoid using glass block near exits and to restrict pedestrian access below or adjacent to a large expanse of glass block by providing a barrier or wide landscaping strip.

Mitigation Examples

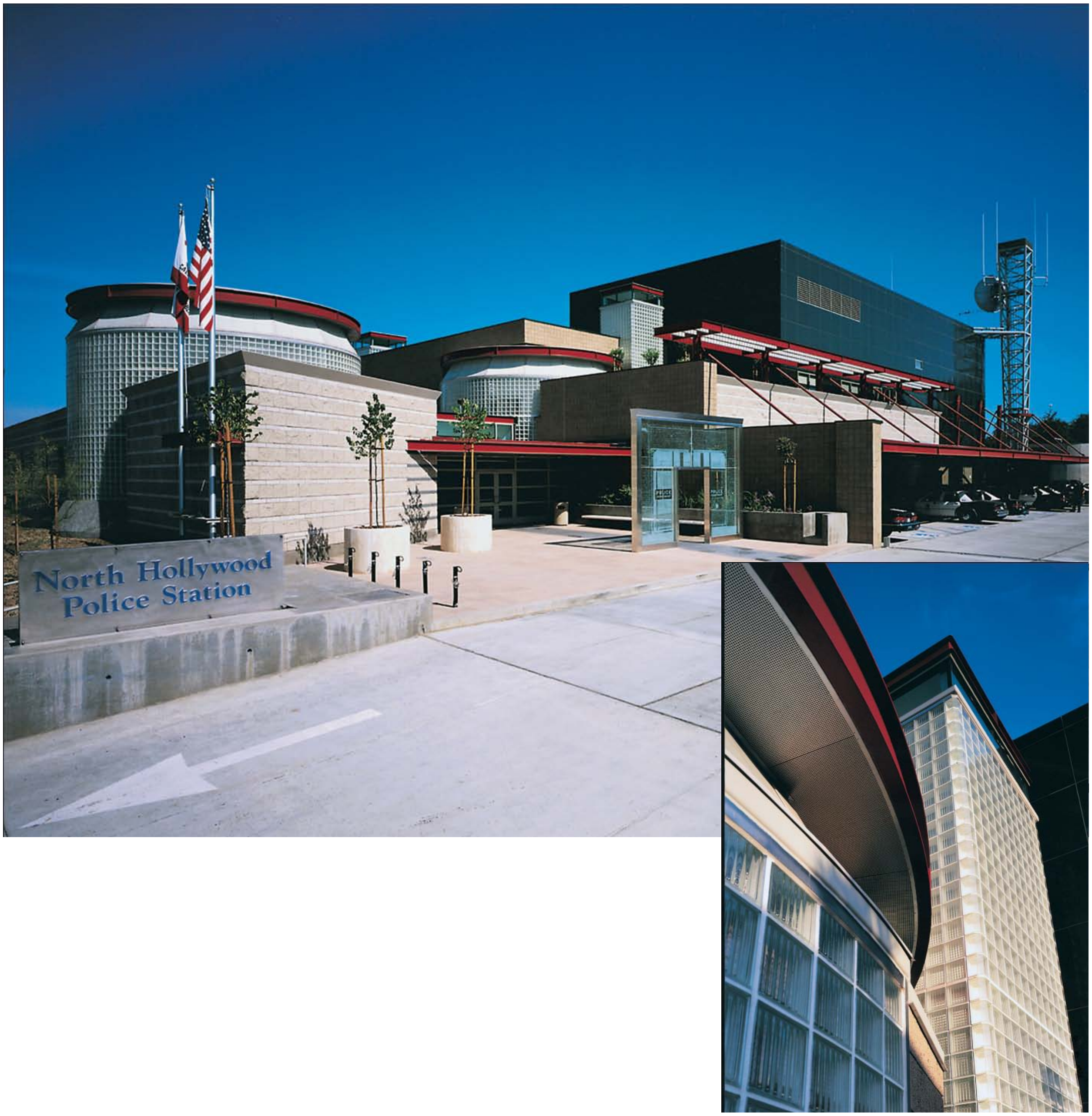


Figure 6.3.1.5-4 Use of glass block panels for select exterior and interior walls at the North Hollywood Police Station in California, utilizing standard details provided by Pittsburgh Corning Glass (Photo courtesy of Pittsburgh Corning Corporation).

Figure 6.3.1.5-5 Glass block panels divided into numerous subpanels at the Chula Vista Police Headquarters, California (Photo courtesy of Pittsburgh Corning Corporation). In addition, the nonbearing glass block panel partition wall is isolated from seismic movement of the building structure.

Mitigation Details

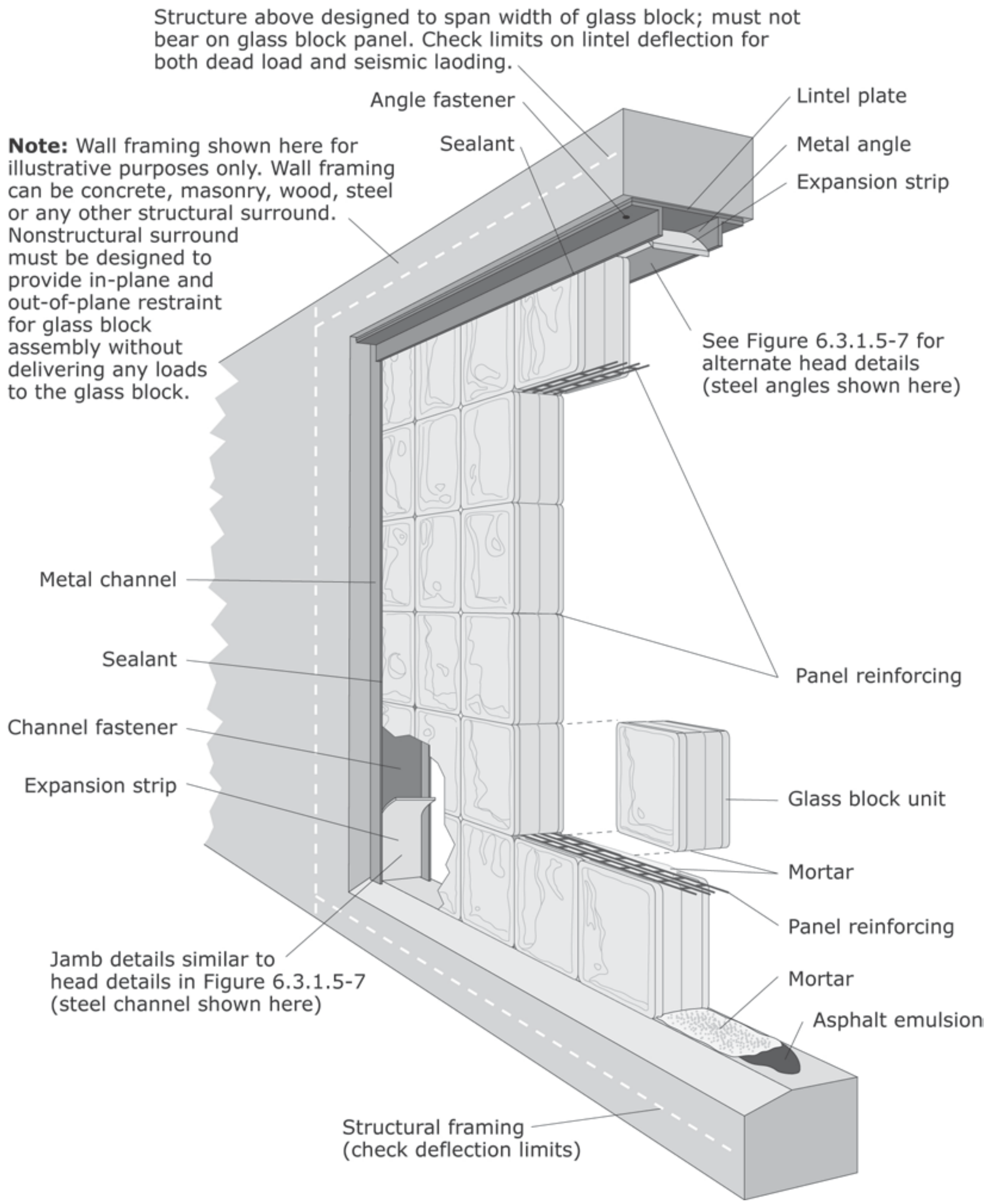
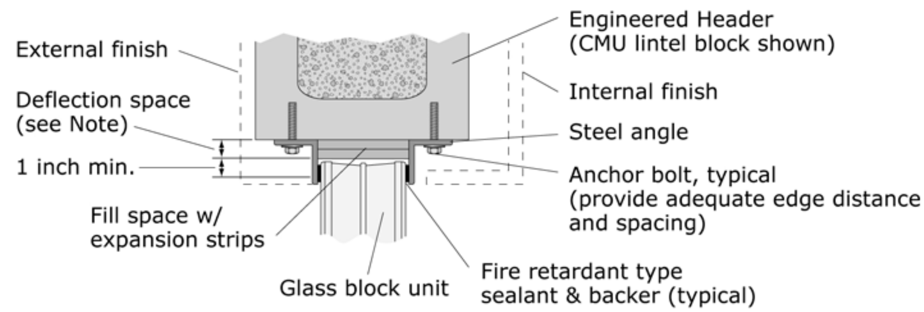
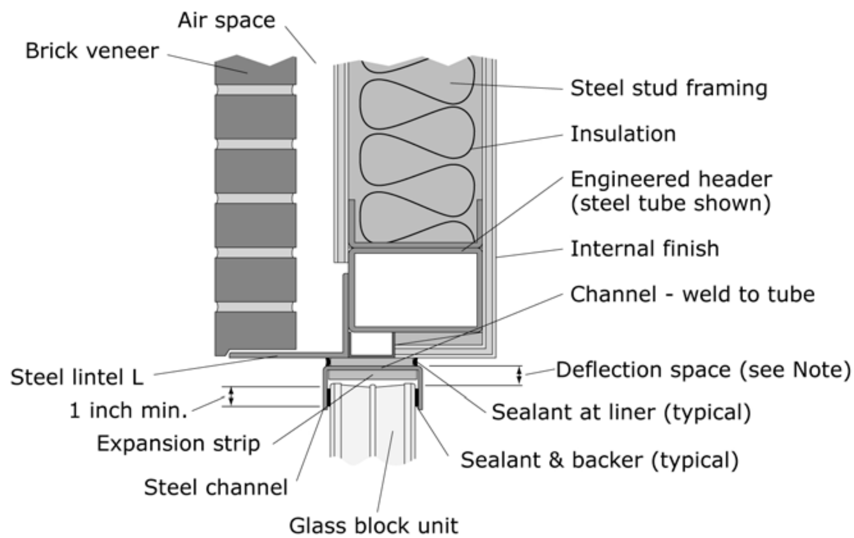


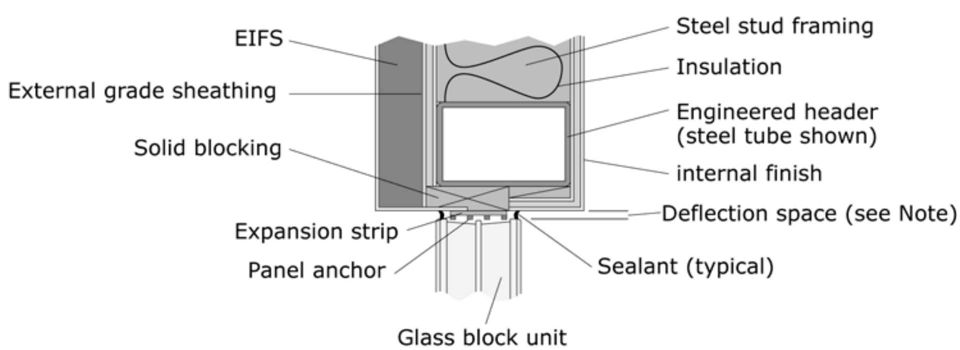
Figure 6.3.1.5-6 Typical glass block panel details (shown here with steel angles or channels to provide lateral restraint (ER).



Head Detail A: Fire rated glass block assembly in CMU wall; lateral restraint provided by steel angles



Head Detail B: Non-rated glass block assembly in steel stud wall with brick veneer; lateral restraint provided by steel channel



Head Detail C: Non-rated glass block assembly in steel stud wall with lightweight finish; lateral restraint provided by panel anchors

Note: The dimension "deflection space" for both jamb and head joints is determined by the anticipated deflection (gravity, seismic, thermal, etc.) of the structural members adjacent to the glass block panel.

Figure 6.3.1.5-7 Alternate head details for glass block panels (jamb details similar) (ER).